EXPERIMENT 2

STUDY OF MAGNETISATION IN A MAGNETIC MATERIAL

Structure

2.1 INTRODUCTION

You have worked with magnets right from your school days. The compass used for finding the north-south direction is the most commonly used magnet. This is a permanent magnet which does not lose its magnetism easily. There are also other types of magnets like electromagnets which produce magnetic field when electric current is passed through them. Such magnets are commonly used in door bells, telephone receivers, electric motors etc.

The choice of magnet is made depending on the application. You have learnt in Unit 14 of core theory course entitled Electricity and Magnetism (BPHCT-133) that all materials are, in some sense, magnetic and exhibit magnetic properties of different kinds and of varying intensities. As you know, all materials can be divided into three main categories, namely, (i) Diamagnetic; (ii) Paramagnetic, and (iii) Ferromagnetic materials.

In practice, we use ferromagnetic materials in most applications. In this experiment, you will magnetise a specimen in the form of iron rod by placing it inside a solenoid and varying the current passing through the solenoid coil. After recording the field (H) and magentisation (M) values, you will draw their curve to obtain the hysteresis loop. From that you will be able to find out various magnetic parameters such as coercive force and coefficient of retentivity for the specimen.

Expected Skills

After performing this experiment, you should be able to

- explain the steps involved in the process of magentisation of a specimen;

- set up the apparatus to obtain the magnetisation curve;
- draw the hysteresis loop for a given iron specimen;
- calculate its coefficient of retentivity; and
- obtain the coercive force.

You will require following apparatus to perform this experiment.

Apparatus required

Iron rod specimen, deflection magnetometer, meter scale, solenoid, compensating coil, dc source (0–3A), ac source (12V, 3A), ammeter (0–3A), rheostat, commutator, and connecting wires.

Before beginning the experiment, let us briefly discuss the basic concepts underlying the magnetisation process.

2.2 MAGNETISATION PROCESS

You have studied in the core course BPHCT-133 that the magnetism in ferromagnets arises due to magnetic domains comprising 10^{17} to 10^{21} atoms occupying typically a volume of 10^{-12} to 10^{-8} m^3. Magnetic moment of a single domain can be very large as it is the sum of many magnetic moment vectors aligned in the same direction.

In a typical ferromagnetic material, the resultant magnetic moments of various domains are randomly oriented. Therefore, it exhibits no net magnetic moment. But when it is placed in an external magnetic field, the resultant magnetic moment in each domain experiences a torque, which tends to orient the associated magnetic moment parallel to the field. In this process, the adjacent domains move against each other and can grow, as shown in Fig. 2.1a. In addition, the magnetic moments of entire domain can also rotate as shown in Fig. 2.1b.

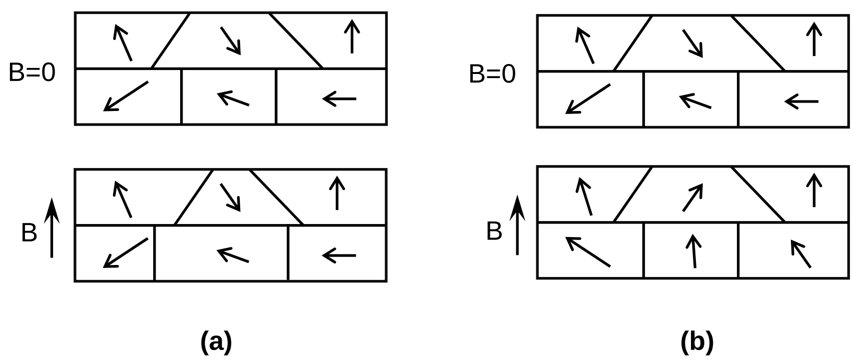

Fig. 2.1: **Magnetic domains in ferromagnetic material under the influence of magnetic field: a) Growth of domains; b) rotation of domains.**

You should note here that removal of the external magnetic field may not destroy the overall alignment completely. In fact, the residual magentisation allows permanent magnetism to exist.

2.2.1 Understanding Hysteresis Loop

Now you know that in its normal state, even a ferromagnetic substance is unmagnetised; and to magnetise it, we need an external magnetic field. In your school physics course, you must have learnt some techniques of magentising a ferromagnetic substance. We can easily magnetise an iron bar by placing it inside a solenoid and passing an electric current though the solenoid. As the current through the solenoid is gradually increased, the magentisation (*M*) of the specimen (iron rod) increases, until it reaches a saturation value. This is illustrated in Fig. 2.2. You will note that initially the magentisation increases slowly but as the current, and hence the field, is increased, it grows more rapidly and reaches saturation ultimately. In Fig. 2.2, the saturation is indicated by point *A*. If the field is now reduced by gradually decreasing the current through the solenoid, *M* does not retrace the original path (curve *OA*). Instead it follows the curve *AB*, as shown in the figure. You may be surprised to know that even when the current, and hence magnetic field in the solenoid, is reduced to zero, some magentisation survives in the specimen. (That is, the ferromagnetic material remembers the past.) In Fig. 2.2 it is shown by *OB*. This value of *M* is known as **remanent magentisation**, denoted by M_r.

You may be tempted to think that once a specimen is magentised, it is not possible to demagentise it. It is not so. We can destroy the magnetisation completely, if we have an opposing field. All that we have to do is to reverse the direction of the current in the solenoid and increase it gradually. In Fig. 2.2, *OC* is a measure of the reverse field required to wipe out magnetism in a ferromagnetic specimen that has been magnetised to saturation. This is called the **coercivity** of the specimen. This value of magnetic field (for $M = 0$) is called the **coercive force** of the specimen, which is denoted by H_C.

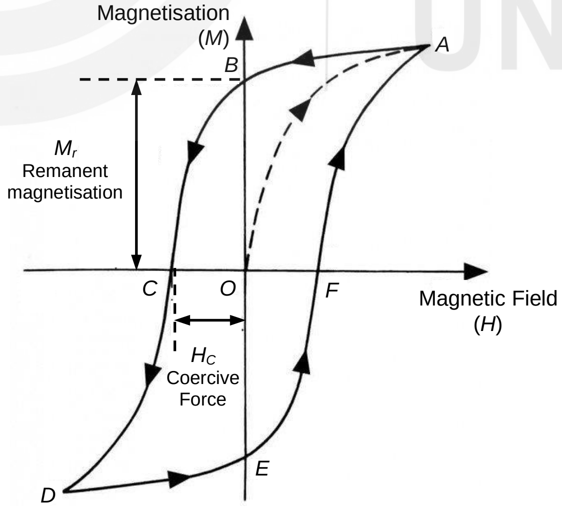

Fig. 2.2: *M-H* **Curve.**

On further increasing the current and taking it to the same maximum value in the reverse direction, the specimen gets magnetised in the opposite direction reaching a saturation value at *D*. By decreasing current (and hence *H*) to zero, reversing and increasing it in again the original direction, the curve *DEFA* is obtained.

You may note from Fig. 2.2 that magnetisation in the specimen does not keep step with the magentising field. Instead, magnetisation tends to persist, i.e., lags behind the magentising field which produces it. This phenomenon is called **hysteresis** (to lag behind). The loop *ABCDEFA* is called the **hysteresis loop**. The area of the loop is a measure of the loss of energy in the specimen per cycle of operation.

In this experiment, you will measure the magnetisation of a thin rod shaped specimen of iron placed along the axis of a solenoid using deflection magnetometer and draw the *M-H* curve. For this you will be required to measure solenoid current i and deflection θ of the tiny magnet in the magnetometer. So it is worthwhile to know the connection of these two measurable quantities with the magnetic field and magnetisation, respectively.

2.2.2 Relation of *i* and θ with *H* and *M*

You have learnt that in the absence of any magnetic field, a freely pivoted magnet (compass needle) orients itself along the Earth's magnetic north-south direction as shown in Fig. 2.3a. This represents the direction of the Earth's (horizontal) magnetic field and is known as the magnetic meridian. Now refer to Fig. 2.3b, which shows a magnetic field along a line perpendicular to magnetic meridian. In the context of this experiment, the specimen of cross sectional area *a* and length 2ℓ (indicated by a solid bar in the in figure) placed in the solenoid (which carries a steady current) provides this magnetic field.

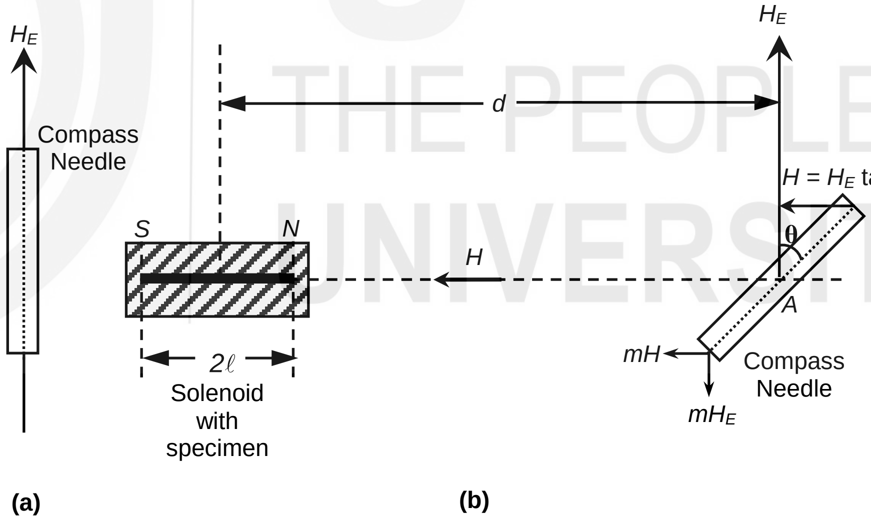

Fig. 2.3: **Orientation of a freely pivoted magnet under a) the Earth's (horizontal) magnetic field; b) an applied magnetic field.**

The applied magnetic field tends to deflect the magnet from its original orientation, whereas the Earth's field tends to off-set this effect. As a result, the compass needle attains an equilibrium position at an angle, say θ with the magnetic meridian. Thus,

$$H = H_E \tan\theta \tag{2.1}$$

where H_E is the horizontal component of Earth's magnetic field. This is known as **tangent law**. It enables us to determine H once θ is known.

Similar to electric dipole comprising a positive and equal negative charge, we can consider the magnet *NS* as a magnetic dipole having magnetic charge $+m$

and –*m*. (This assumption is entirely made up for convenience, because you know that isolated magnetic charges/monopoles do not exist.) Under this assumption, magnetic field due to magnet *NS* at point *A* (centre point of the compass needle) can be written as

$$H = \frac{m}{(NA)^2} - \frac{m}{(SA)^2}$$

$$= m\left[\frac{1}{(d-\ell)^2} - \frac{1}{(d+\ell)^2}\right]$$

$$= \frac{4m\ell d}{(d^2-\ell^2)^2}$$

$$= \frac{4(M\ell a)d}{(d^2-\ell^2)^2} \qquad (2.2)$$

Magnetic moment of the magnetic dipole
$NS = m.2\ell$

Volume of the magnet
$NS = 2\ell.a$

By definition,

Magnetisation,

$$M = \frac{\text{Magnetic moment}}{\text{Volume}}$$

Hence,

$$M = \frac{2m\ell}{2\ell a} = \frac{m\ell}{\ell a}$$

$$\therefore m\ell = M\ell a$$

where M is the magnetisation of specimen *NS* with area of cross section *a* and length 2ℓ. On comparing Eqs. (2.1) and (2.2) we can write

$$\frac{4M\ell ad}{(d^2-\ell^2)^2} = H_E \tan\theta$$

or

$$M = \frac{H_E\,(d^2-\ell^2)^2}{4\ell ad}\tan\theta \qquad (2.3)$$

That is, M is directly proportional to tan θ.

$$M \propto \tan\theta \qquad (2.4)$$

From Unit 14 of core theory course BPHCT-133, you know that the magnetic field intensity *H* directly depends on the current *i* through the solenoid [Refer to Eq. (14.18)]. That is we can write,

$$H \propto i \qquad (2.5)$$

In case of solenoid with *n* number of turns per centimeter, the field intensity in the units of ampere per meter is given by

$$H = 100 \times n \times i \qquad (2.6)$$

Therefore, from Eqs. (2.4) and (2.5), it is evident that an experimental plot of tan θ versus *i* is equivalent to the plot of *M* versus *H*.

The value of horizontal component of earth's magnetic field H_E varies from place to place. You should consult your counselor for the exact value at your place. Typical values for some places in India in the units of micro-tesla are given below:
Delhi: 34.11 μT
Mumbai: 38.22 μT
Kolkata: 38.09 μT
Chennai: 40.49 μT

You can convert the field expressed in μT into Am^{-1} by multiplying it by 0.7958.

Now that you are familiar with the theoretical background, we hope that you are ready to perform the experiment. You should now get acquainted with the apparatus you will need to perform the experiment.

2.3 FAMILIARISATION WITH THE APPARATUS

In this experiment you will use a deflection magnetometer, a solenoid and a compensating coil. We now describe each of these.

a) ***Deflection Magnetometer***

Refer to Fig. 2.4. It shows a deflection magnetometer, which consists of a magnetic compass box with plastic casing, mirror base and a glass top. A tiny permanent magnet (*CD*) is pivoted at the centre of the box (the red dot on magnet indicates north pole). A long aluminium pointer (*AB*) is attached at right angles to the magnet. The ends of the aluminium pointer move over a circular scale divided in each quadrant from 0° to 90°. This enables us to know the deflection of the magnet under the influence of Earth's magnetic field and the external magnetic field.

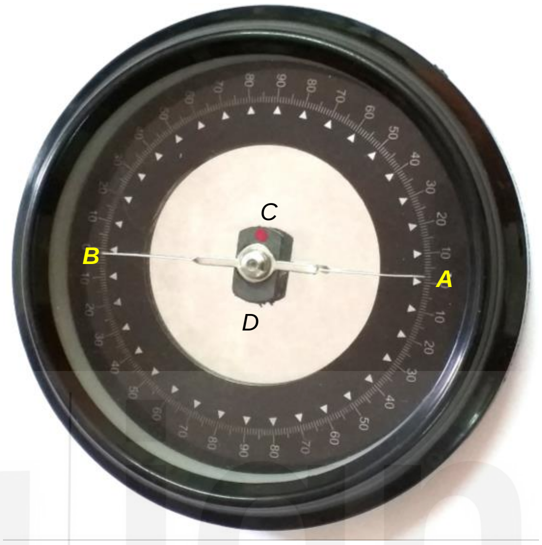

Fig. 2.4: **Deflection magnetometer:** *AB* **is an aluminium pointer and** *CD* **is a tiny magnet.**

b) ***Solenoid***

A solenoid is a helix of wire wound around a 25 to 30 cm long hylem tube. More than one layer of turns can be wound on the tube. A rod of the given specimen can be easily inserted so that it is along the axis of the solenoid, as shown in Fig. 2.5.

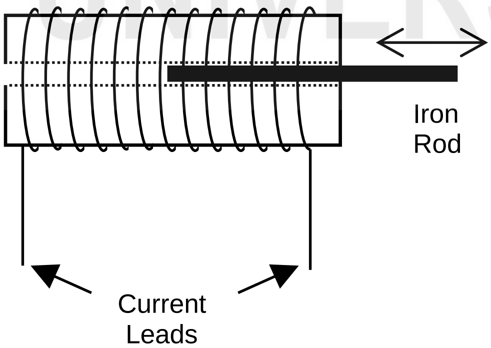

Fig. 2.5: **Solenoid coil with current leads. An iron rod specimen can be inserted into the solenoid.**

c) ***Compensating Coil***

The compensating coil is another uniform helix of wire wound on a hylem tube. This is about 10-20 cm long and may carry more than one layer of turns.

You know that current passing through a solenoid gives rise to a magentising field along the axis of the solenoid. If any specimen is introduced along the axis of the solenoid, a magnetic field due to magnetisation of that specimen comes into existence.

To depict the relation between intensity of magnetisation and the magentising field, you are required to observe the effect of the specimen on the tiny magnet of the magnetometer. Thus, you have to initially balance the effect of the magnetic field due to current though the solenoid, on the magnetometer. This is ensured by using a compensating coil. Before starting the experiment, you should ensure that initially the specimen should not have any residual magnetism. Why? How will you test it? Discuss it with your Counsellor and record your discussion.

With this preliminary knowledge you can now perform the experiment.

2.4 MEASUREMENT OF MAGNETISATION USING DEFLECTION MAGNETOMETER

Follow the procedure described below to perform the experiment.

1. Remove all magnets (if there are any) and put the deflection magnetometer on the working table. Mark the positions corresponding to the ends of the pointer on the table using a chalk as shown in Fig. 2.6a**.** Remove the magnetometer and join the chalk marks by a straight line and extrapolate it as shown in Fig. 2.6b. This defines the magnetic east-west line in the laboratory. A line drawn perpendicular to it will represent the magnetic meridian.

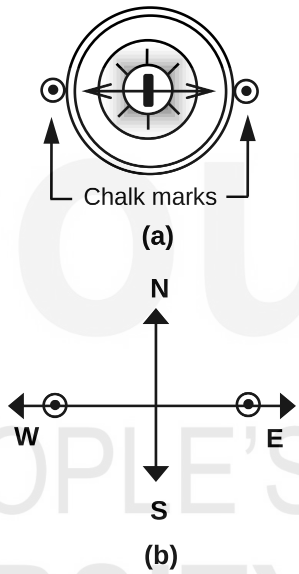

Fig. 2.6: **Marking magnetic meridian: a) Chalk marks corresponding to the ends of the pointer depict east-west; b) the magnetic meridian is normal to the east-west line.**

2. Refer to Fig. 2.7. It depicts the experimental set-up in which the solenoid *S* is placed horizontally on the working table with its axis perpendicular to the magnetic meridian and the compensating coil *C* is coaxial with the solenoid. Note that the compass box of the deflection magnetometer (*DM*) is kept between the solenoid *S* and the compensating coil *C*. You should also take care that the axes of the two coils are in the same horizontal plane as the needle of the compass.

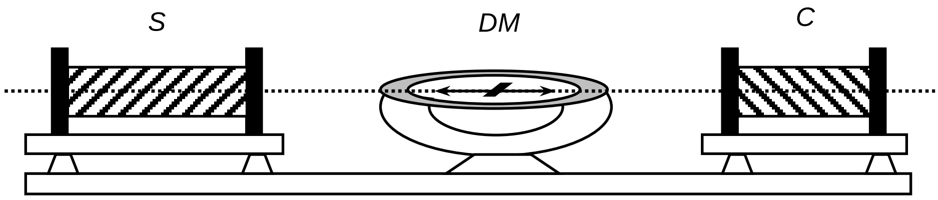

Fig. 2.7: **Experimental set-up. The solenoid** *S* **and the compensating coil** *C* **are on either side of the deflection magnetometer** (*DM*)**.**

3. Rotate the magnetometer slowly in its groove so that the ends of the needle of the compass read zero-zero on the circular scale.

4. The circuit diagram to study variation of field with current is shown in Fig. 2.8. The solenoid is connected in series with the compensating coil through a commutator, to a power supply, ammeter and rheostat. You should place the solenoid so that it is at a larger distance from the centre of the magnetometer compared to the compensating coil. This is to ensure that the deflection of the needle in the compass box of the magnetometer

A *commutator* is a component used for manually reversing the current direction in the circuit by changing the position of its contact strips.

is less than 70° for the maximum magnetisation of the specimen. The direction of current in the compensating coil *C* is taken such that its field opposes the field due to the solenoid.

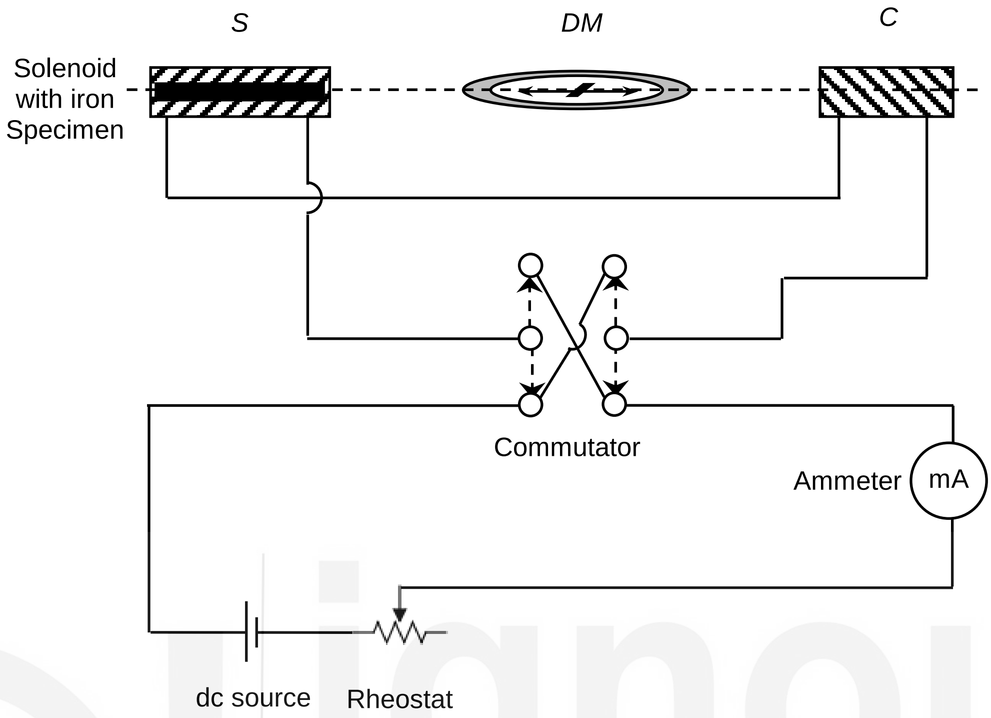

Fig. 2.8: **Circuit diagram to study variation of deflection in the magnetometer with current.**

5. Pass a current of about 3A through the solenoid by adjusting the position of the slider of the rheostat. (It should be sufficient to magnetise the specimen to saturation). **Do not place the specimen in the solenoid yet**. Adjust the position of the compensating coil shifting it along the axis (without disturbing the solenoid) so that magnetometer shows zero deflection. Reverse the current with the commutator and ensure that there is no deflection. In this setting, the effect of the field due to the current in the solenoid at the centre of the magnetometer is off-set by the field created due the current in the compensating coil. You should make a similar check for other values of current as well. Now reduce the current in solenoid slowly to zero.

6. Now insert the unmagnetised specimen (iron rod) inside the solenoid completely (Refer to Fig. 2.5). Switch on the current source and gradually increase the current through the solenoid to the saturation value, say, 3A. Note the deflection in the magnetometer. In no case should the deflection exceed 70°, which corresponds to saturation value of solenoid current. If the deflection is greater than this value, you should adjust the distance between the magnetometer and the solenoid. To do so, you should slowly reduce the solenoid current to zero. Remove the specimen from the solenoid and keep it far away from the set up. Increase the distance of the solenoid from the centre of the magnetometer by a few centimeters and repeat Steps 5 and 6.

7. It is quite likely that the iron rod acquired (retained) some magnetism while you were testing for maximum value of deflection in the above steps. But the specimen should be unmagnetised when you begin your experiment.

So to demagentise the specimen you should pass an alternating current (ac) of about 2A through another solenoid with the specimen placed inside it along its axis and reduce the current gradually.

8. Place the demagentised (unmagnetised) specimen inside the solenoid. Switch the current on and gradually increase it to 0.25 A by adjusting the rheostat. Record the readings of both ends of the pointer in Observation Table 2.1. Increase the current slowly to 3 A in steps of 0.25 A and note the readings of the pointer every time. You may observe that after certain current value the magnetometer deflection is constant for two (or more) successive readings. Do not be surprised. It can happen when the specimen is magnetically saturated. We expect that normally a current of 2.5 A to 3 A will be needed to obtain magnetic saturation.

9. Once you have reached saturation value, start reducing the current in the same steps of 0.25 A. Record the values of deflection of the pointer till the current is zero. Do you obtain zero deflection in the magnetometer when there is no current in the circuit? The non-zero deflection signifies that the specimen retains some magnetism.

10. Next reverse the direction of the current in the circuit using the commutator. Increase the current in steps of 0.25 A. For some value of current, the deflection will be zero, that is the specimen will be demagentised (H = 0). Continue increasing the current till saturation is reached with opposite polarity in the specimen. Keep recording your reading in the Observation Table 2.1. Next reduce the current in same steps till it becomes zero. (Now the specimen will start getting demagentised). Record the magnetometer readings for all values of current in the Observation Table. As before, you will observe that the deflection in the magnetometer is not zero, even though the solenoid current is zero.

11. To remove this retained magnetism, reverse the direction of current using the commutator. You must complete this cycle by increasing the solenoid current to the saturation value.

12. Draw a smooth curve with the current along the x-axis and the tangent of the deflection (tan θ) along the y-axis. It is not necessary for the curve to pass through all the points.

Observation Table 2.1: Deflection in magnetometer with current

Number of turns per centimeter length of the solenoid, n	=
Length of the specimen, 2ℓ	=…… m
Radius of the specimen, r	=…… m
Area of cross-section of specimen, $a = \pi r^2$	=…… m^2
Distance of the centre of specimen from the magnetometer, d	= ……. m

Current through the solenoid i (A)	Deflection											
	Current Increasing				Current Reversed				Current again Reversed			
	θ_1	θ_2	Mean θ	$\tan\theta$	θ_1	θ_2	Mean θ	$\tan\theta$	θ_1	θ_2	Mean θ	$\tan\theta$
0.25												
0.50												
0.75												
1.00												
1.25												
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1.00												
0.75												
0.50												
0.25												
0.00												

2.5 DETERMINATION OF MAGNETIC PARAMETERS OF A SUBSTANCE

To obtain retentivity, determine the value of $\tan\theta$ (say, $\tan\theta_r$) corresponding to the point *B* or *E* in the hysteresis curve (Refer to Fig. 2.2). Substitute this value of $\tan\theta_r$ in Eq. (2.3) to get the value of retentivity.

$$\text{Retentivity} = \frac{H_E\,(d^2 - \ell^2)^2}{4\ell a d}\tan\theta_r$$

Similarly note the value of current (i_C) corresponding to point *C* or *F* in the *M*-*H* graph. Then coercivity can be obtained from Eq. (2.6).

$$\text{Coercivity} = H_C = 100 \times n \times i_C$$

Result:

i) Retentivity = ……………… Am^{-1}

ii) Coercivity = ……………… Am^{-1}

SAQ 1 - Effect of Earth's Magnetic Meridian

Place the solenoid so that its axis is along the magnetic meridian. Can you perform the experiment now?

In this experiment, you have drawn the hysteresis curve for an iron specimen and used it to obtain its retentivity and coercivity. Discuss the utility of these parameters for determining the use of the specimen given to you as a permanent magnet or as on armature of electric motor or as a core of the transformer with your Counsellor and record the same in your laboratory notebook.